

FINITE ELEMENT ANALYSIS OF AUTONOMOUS UNDERWATER GLIDER

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ABSTRACT

Autonomous Underwater Glider is an emerging concept for the oceanographic investigations. The increased strength to weight ratio of laminated composite makes it a suitable material for the construction of underwater gliders. Laminated composites have reduced transverse shear stiffness and hence the transverse shear deformations play a major role in the analysis. The present study has been conducted on the components of underwater gliders, the results of which could be used in the design of the same. Estimation of the linear static response and buckling load of the components of underwater glider using finite element software ANSYS has been reported in this paper. This analysis procedure and results are useful in the design of underwater gliders.

KEYWORDS: Autonomous Underwater Glider, Laminated Fiber Reinforced Composite, Linear Elastic Analysis, Buckling Analysis

Nomenclature

E	Young's modulus of an isotropic material
E_1, E_2, E_3	Young's modulus in local 1,2, 3 directions
G_{12}, G_{31}, G_{23}	shear moduli in 1-2, 3-1,2-3 planes.
R	radius of curvature
$\overline{M}_{\phi\phi}$	nondimensionalised moment in meridional direction
$\overline{N}_{\phi\phi}$	nondimensionalised in plane force in meridional direction
a	length of the cylindrical shell panel/ length of a spherical shell panel
b	breadth of the cylindrical shell panel
h	thickness of the shell
p	hydrostatic pressure
q_{cr}	critical buckling pressure
\overline{q}_{cr}	non dimensionalised critical buckling pressure
w	transverse/radial deflection
\overline{w}	non dimensionalised transverse/radial deflection
α	half of the angle subtended by the cylindrical shell panel at the centre
ν	Poisson's ratio of an isotropic material.

$\nu_{12}, \nu_{13}, \nu_{23}$ - Poisson's ratio corresponding to 1-2, 1-3 and 2-3 planes.
 σ_θ, σ_l - stresses in the circumferential and longitudinal directions

INTRODUCTION

Autonomous Underwater Gliders (AUG) are self propelled, slow moving subsea vehicles widely used for inspecting the ocean habitats and the living organisms. These vehicles dive through the ocean utilizing the combined effect of buoyancy, and lift and drag forces acting on them, creating a pressure difference between the top and bottom surfaces of these gliders. Since these are submerged bodies, the predominant force acting on their surface is the hydrostatic pressure which shoots up with the diving depth of AUG. The hydrostatic pressure acts on all the exposed components viz., the pressure hull and the wings.

The pressure hull usually consists of cylindrical body with spherical or hemi ellipsoidal end closure. All the machine components and the equipments are housed inside the pressure hull. The external hydrostatic pressure causes compressive stress resultants in the shell membrane leading to buckling failure of pressure hull. The design thickness of the Laminated Fiber Reinforced Composite (LFRC) pressure hull shell is much lower than that required by the conventional pressure hull material such as steel, aluminium and titanium. The reduction in thickness enhances the possibility of buckling failure of LFRC shells. The scheme of structural analysis of thin shells made of LFRC has to be modified by incorporating the effect of transverse shear deformations on various stress resultants. Transverse shear stresses are absent for homogeneous, isotropic shells of revolution, whereas these stresses varies across the thickness and remains zero on the inner and outer surfaces of the pressure hull made of LFRC shells. Hence various stresses developed in a LFRC thin shell of revolution is longitudinal and circumferential stresses and transverse shear stresses.

The wings of AUG acts as thin shell panel and these are subjected to pressure difference on top and bottom surface of wings; the main force component responsible for the propulsion of AUG. The efficiency of AUG can be increased by increasing the surface area of wings and this subsequently can cause buckling failure. The situation worsens with fact that there is reduction in design thickness by virtue of using carbon fiber composite material [Osse, 2007(a and b)] .

The stress resultants arising from the pressure difference acting on the wing panels are the relevant quantities for the structural design and these are evaluated using structural analysis. It becomes necessary to predict state of responses including transverse shear stresses and deformation as well as the buckling load on structural components of AUG for a safe design. These components do not pertain to the regular geometry for which closed form solutions are readily available. Finite element method has been generally resorted to in such situations. This paper addresses the utility of finite element method for the structural analysis of components of AUG.

FINITE ELEMENT SOFTWARE

The software used for the structural analysis of AUG is the ANSYS. The element used for the present analysis is SHELL281 of ANSYS element family (ANSYS Release Notes, 2009) which is an eight noded element with six degrees of freedom per node viz., the three translations and rotations. It can take a quadrilateral or a triangular form, but the accuracy of the results are reduced with the use of triangular elements. The element can be used as membrane element also by considering the membrane option and for both linear and geometrically and materially nonlinear analysis. The element can be used for analyzing laminated composite structures. The first order shear deformation theory is used in deriving this element. The geometry of SHELL281 has been shown in Figure.1.

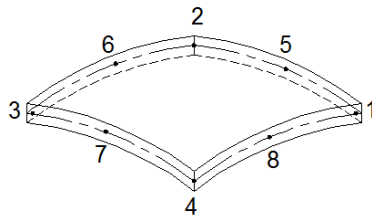


Figure 1: Geometry of SHELL281 of ANSYS Element Family

NUMERICAL INVESTIGATIONS

Numerical investigations envisaged in the present study cover the linear and buckling analysis of components of AUG viz., the wing which is a curved panel and the pressure hull which is a circular cylinder. However a few validation problems are attempted before taking the structural components of AUG.

Linear Elastic Analysis

Validation Problems

Two problems of orthotropic shallow shell panel and isotropic cylindrical shell panel have been analysed using the software and has been validated using existing solutions.

Orthotropic Shallow Shell

A nine layered laminated graphite-epoxy shallow shell reported by Jeyachandrabose and Kirkhope [1985] , has been considered in the present analysis. They have validated their shell finite element using the results presented by Noor and Mathers [1975]. The same has also been referred to in the present analysis. The geometry of the shallow shell has been shown in Figure.2. The shell has been considered as simply supported on the edges. The features of the shell have been as follows.

$R=10000\text{mm}$, $a=1000\text{mm}$, $h=10\text{mm}$ Fiber orientations-0/90/0/90/0/90/0/90/0

$E_1=162\text{ GPa}$, $E_2 = 4.05\text{ GPa}$, $G_{12}=2.43\text{ GPa}$, $\nu_{12}=0.25$, Hydrostatic pressure = 10 kPa

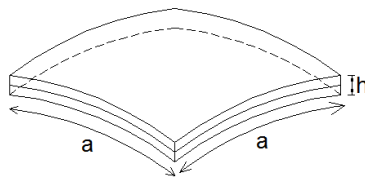


Figure 2: Geometry of the Shallow Shell

The results of the linear elastic analysis are presented in Table 1.

Table 1: Static Response of Orthotropic Shallow Shell

	Authors(Using ANSYS)	Jeyachandrabose and Kirkhope [1985]	Noor and Mathers [1975]
$\bar{w} = \frac{wE_2h^3}{pa^4} 10^3$	2.699	2.707	2.713

$\overline{N_{\varphi\varphi}} = \frac{N_{\varphi\varphi}}{pa}$	3.290	2.835	3.005
$\overline{M_{\varphi\varphi}} = \frac{M_{\varphi\varphi}}{pa^2} 10^2$	6.320	5.248	5.239

Table 1 indicates that the deflection calculated by ANSYS has been in good agreement with the report results, while there has been a variation in the stress resultants computed by the ANSYS and the existing results.

Isotropic Cylindrical Shell Panel

A clamped isotropic cylindrical shell panel [Reddy, 1997] has been considered. The shell panel has following features.

$R = 100$ in., $a = 20$ in., $h = 0.125$ in., $\alpha = 0.1$ radian, $E = 0.45 \times 10^6$ psi, $\nu = 0.3$, transverse pressure = 0.04 psi. The geometry of the cylindrical panel has been shown in Figure.3.

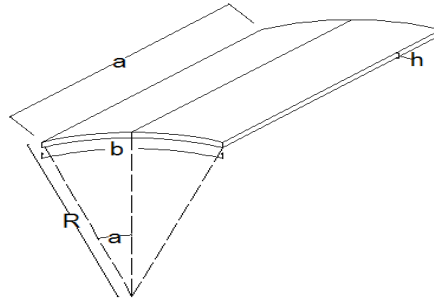


Figure 3: Geometry of the Cylindrical Shell Panel

The transverse deflection at the centre of clamped cylindrical shell panel under uniformly distributed transverse loading has been found to be 0.1134 in. using ANSYS while the same has been reported as 0.1142 in. by Reddy (1997).

Components of AUG

Wing

Experiments on models of gliders with various wing shapes, such as flat, curved, various wing angles have been reported by Drew [2002]. The above experiments have been conducted to study the effect of various wing shapes on the speed of the gliders. The actual dimensions of the wing model are available and are being adopted from the paper by Drew for the analysis using ANSYS. The features of the wing model are specified as follows.

The wing is constructed of PVC material. The length of the wing is 158.75 mm, wing chord is 63.5mm and the thickness of wing shell is 5mm. For PVC material $E = 2895$ MPa, $\nu = 0.41$. Geometry of the wing has been shown in Figure 4

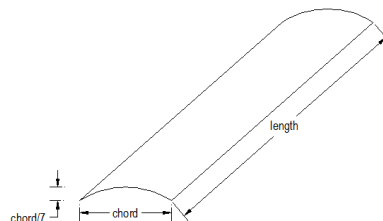


Figure 4: Geometry of the Wing

Since the wing is a cantilever from the nodes at pressure hull, one end of the finite element model is given clamped and the other as free end. The hydrostatic pressure is 1 kPa. The transverse deflection at the free end has been found as 0.767mm. The circumferential and the longitudinal stresses at the clamped end has been obtained as 0.884 Mpa and 2.16 Mpa respectively.

Cylindrical Pressure Hull

Laminated composite cylindrical pressure hulls have been experimentally tested for the development of pressure hull for the Deepglider [Osse, 2007(a and b)]. The actual dimensions of the cylindrical pressure hull have been adopted from the same. The characteristic features of the pressure are as follows.

Length of the glider-180cm, Maximum diameter =30cm. Thickness of the shell= 2 cm. Material of the hull- carbon fiber composite material. $E_1=11.7$ GPa, $E_2=88.3$ GPa, $E_3=42.3$ GPa, $G_{12}=5.11$ GPa, $G_{13}=4.23$ GPa, $G_{23}=8.21$ GPa, $\nu_{12}=0.044$, $\nu_{23}=0.157$, $\nu_{13}=0.113$

Lamination scheme- $(90_2/0_2/90_2/-45/90_2/45/90_2/0_2)_2(90_2/0/90_2/0/90/-45/45/0/45/-45/90/0/90_2/0/90_2) (90_2/0_2/90_2/-45/90_2/45/90_2/0_2)_2$. Hydrostatic pressure= 60 MPa .

The radial displacement at the centre of the pressure hull has been found to be 1.8mm, while the circumferential and longitudinal stresses at the centre of the cylindrical pressure hull has been obtained as 686.9 Mpa and 29.7 Mpa.

Buckling Analysis

Validation Problem

An orthotropic cylinder has been analysed to compute the linear buckling pressure and the same has been validated using reported results.

Orthotropic Cylindrical Shell

An orthotropic cylindrical shell as reported by Cagdas and Adali (2011) has been analysed to calculate the linear buckling pressure. The cylindrical shell has following attributes and is adopted from the above paper.

The radius (R) of the shell is 1000mm and the length 10000mm. The thickness (h) of the cylinder has been taken as 47.62mm. The radial and circumferential deformations have been arrested at both the ends and the axial displacement has been arrested at the one end. The properties of the material glass epoxy used for the analyses are as follows:

$$E_1= 57 \text{ MPa}, E_2 = 14 \text{ MPa}, G_{12} = 5.7 \text{ MPa}, G_{13} = 5.7 \text{ MPa}, G_{23}=4.3 \text{ MPa}, \nu_{12} = 0.277$$

The same problem has been solved by Kardometeas (1996) who has obtained a classical result for the problem and Cagdas and Adali have validated their output using this classical method. The nondimensional critical linear buckling

pressure $\left(\overline{q_{cr}} = q_{cr} R^3 / E_1 h^3\right)$ has been found to be 0.249 using ANSYS. Kardometeas (1996) reported a value of 0.281 and Cagdas and Adali presented a value of 0.399 for the same problem.

Orthotropic Shallow Shell

The orthotropic shallow shell mentioned in section 3.1.1 is considered for the linear buckling analysis. Using same element mesh in ANSYS, the critical linear buckling pressure has been obtained as 67.102 kPa

Components of AUG

Wing of an AUG

Buckling analysis of the wing mentioned in section 3.1.2 has been conducted and the critical linear buckling pressure has been found to be 102.470 kPa.

Cylindrical Pressure Hull

Buckling analysis of cylindrical pressure hull referred to in section 3.1.2 has been carried out and the critical linear buckling pressure has been found to be 1511MPa.

CONCLUSIONS

The analysis using ANSYS give acceptable solutions for deflections in the linear analysis while the stress resultants show a variation from the reported results. Regarding the prediction of the critical buckling pressure of the orthotropic cylindrical shell, the values has been found close to the classical solution than the finite element analysis presented by Cagdas and Adali (2011). Finite element software ANSYS has been successfully used for the prediction of elastic response and critical buckling pressure of structural components of AUG.

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